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A Summary of the JANNAF Workshop on Methods for Exchange of Gun Propellant Burning Rate Information

Frederick W. Robbins
John A. Vanderhoff

ARL-TR-127 May 1993

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U.S. Army Research Laboratory
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A workshop sponsored by the JANNAF Propellant Development and Characterization Subcommittee was held at the U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD on 21–22 July 1992. The purpose of the workshop was to define methods for exchanging propellant burning rate (BR) information. A recently developed BR reduction code (BRLCB) has been subject to testing, and a major item of progress for the workshop was to accept BRLCB as an interim preferred closed bomb code for data exchange purposes. Additionally, workshop attendees agreed that the input thermochemistry for BRLCB should be calculated for a 0.2 loading density.

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PREFACE

On 30 September 1992, the U.S. Army Ballistic Research Laboratory (BRL) was deactivated and subsequently became part of the U.S. Army Research Laboratory (ARL) on 1 October 1992.

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1. INTRODUCTION

A workshop sponsored by the JANNAF Propellant Development and Characterization Subcommittee was held at the U.S. Army Ballistic Research Laboratory (BRL), Aberdeen Proving Ground, MD, on 21–22 July 1992. The purpose of the workshop was to: 1) define a model for determining gun propellant closed bomb burning rates (BR); 2) choose a "standard" BR reduction computer code(s); and 3) make it easy for propellant manufacturers to aid the research and development community by suggesting desired BR information and how it may be economically obtained and disseminated (e.g., on propellant description sheets). A list of attendees is given in Table 1.

Table 1. Workshop Attendees

Name	Organization
Frederick Robbins	BRL
John Vanderhoff	BRL
Anthony Kotlar	BRL
Douglas Kooker	BRL
Pamela Kaste	BRL
Robert Lieb	BRL
William Oberle	BRL
Caledonia Henry	BRL
Claire Selawski	BRL
Shirley Newton	BRL
Didier Devynck	BRL
Harry Bates	BRL
Andrew Brant	BRL
Theresa Keys	BRL
John Domen	ARDEC
Kenneth Klingaman	ARDEC
Jerome Rubin	ARDEC
Robert Rast	NSWC-IH
Sharon Boyle	NSWC-IH
Susan Peters	NSWC-IH
Edward Chan	NSWC-IH
Alice Atwood	NAWC
J. Jeff Brown	Penn. State Univ.
James Kennedy	Alliant Techsystems
D. A. Worrell II	Hercules Radford
Edward Sanford	Hercules Radford
Richard Cartwright	Hercules Kenvil
Dennis Worthington	Olin Ordnance

Table 1. Workshop Attendees (continued)

Name	Organization
Neale Messina	PCRL
Otto Heiney	Rocketdyne
David Dillehay	Thiokol-Longhorn
Rodney Willer	Thiokol-Elkton
James Barnes	Veritay
Eli Freedman	Eli Freedman & Associates

2. PRESENTATIONS

Fred Robbins (BRL) presented a summary of the usual assumptions incorporated into closed bomb BR reduction models. Discussions resulted in the addition of several more assumptions (Table 2). Some not so universal characteristics (Table 3) and potential data acquisition differences were also presented (Table 4).

Table 2. Usual Assumptions for Closed Bomb Burning Rate Reduction Models

- Well-stirred reactor
- No gradients in temperature, concentration, velocity, or pressure
- No grain motion (solid kinetic energy is negligible)
- Stored thermal energy is negligible
- Igniter all burnt at time zero
- Covolume equation of state
- Dalton's law of partial pressures
- No work done on the bomb
- Single propellant
- $dm/dt=\rho*s*(dx/dt)$
- Constant heat capacity (constant volume) over range of interest
- Constant solid propellant density
- Propellant burns normal to its grain surface
- All grains are uniform
- Thermodynamic equilibrium exists among the reaction products (no kinetics)
- Instantaneous flame spreading
- All gas phase combustion products (no solids)
- Homogeneous solid propellant with no large voids

These assumptions are incorporated into an analytic set of equations which can be solved for BR in a number of different ways.

Table 3. Not So Universal Characteristics

• Heat loss
• Smoothing
• Numerical techniques
• Thermochemistry
• Units
• Layered/deterred capabilities
• Variable propellant density
• Surface area calculations given BR
• Variable thermochemistry
• Variable time step
• Blowout bomb analysis

Table 4. Potential Data Acquisition Differences

• Electronic filters
• Gauges and calibration procedures
• Bomb sizes
• Bomb geometries
• Maximum operating pressures
• Ignition trains
• Squibs
• Propellant loading configurations
• Sampling interval
• Number of bits stored per sample

Doug Kooker and Bill Oberle (BRL) discussed the structure, governing equations, and solution technique used in version 3 of BRLCB, a recently developed BR reduction code. BRLCB will perform BR reductions for uniform, layered, and/or deterred propellants. It can also be used to obtain surface areas as well as the pressure-time curve given a BR description. The code does not use dP/dt for the calculation of the BR but deduces it directly from the pressure-time curve. The code was verified with analytic solutions and with its own generated (synthetic) pressure time curves. Comparisons with other BR reduction codes were also presented. All comparisons were excellent. Effects of data word length were found to be noticeable. This word length effect suggests that a 16-bit word length would be much better than a 10-bit word length; a 10-bit word length introduces approximately a 2% error whereas 16-bit words have errors about 2 orders of magnitude less. This study of maximum error is based on a comparison against an analytic solution for the pressure-time curve (see Figures 1 and 2).

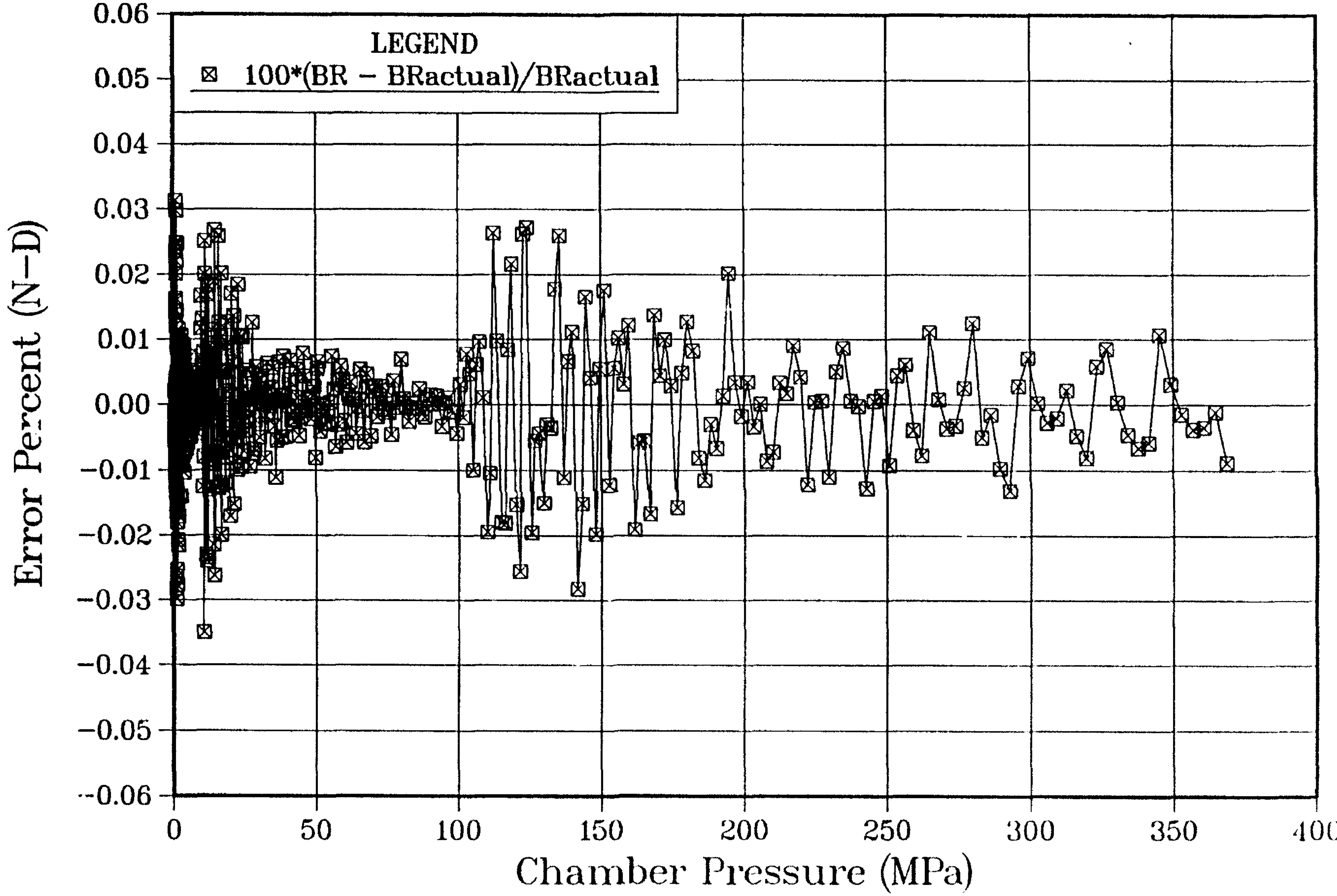

Figure 1. Synthetic test case: Percent error in BR using BRLCB with six-place accuracy.

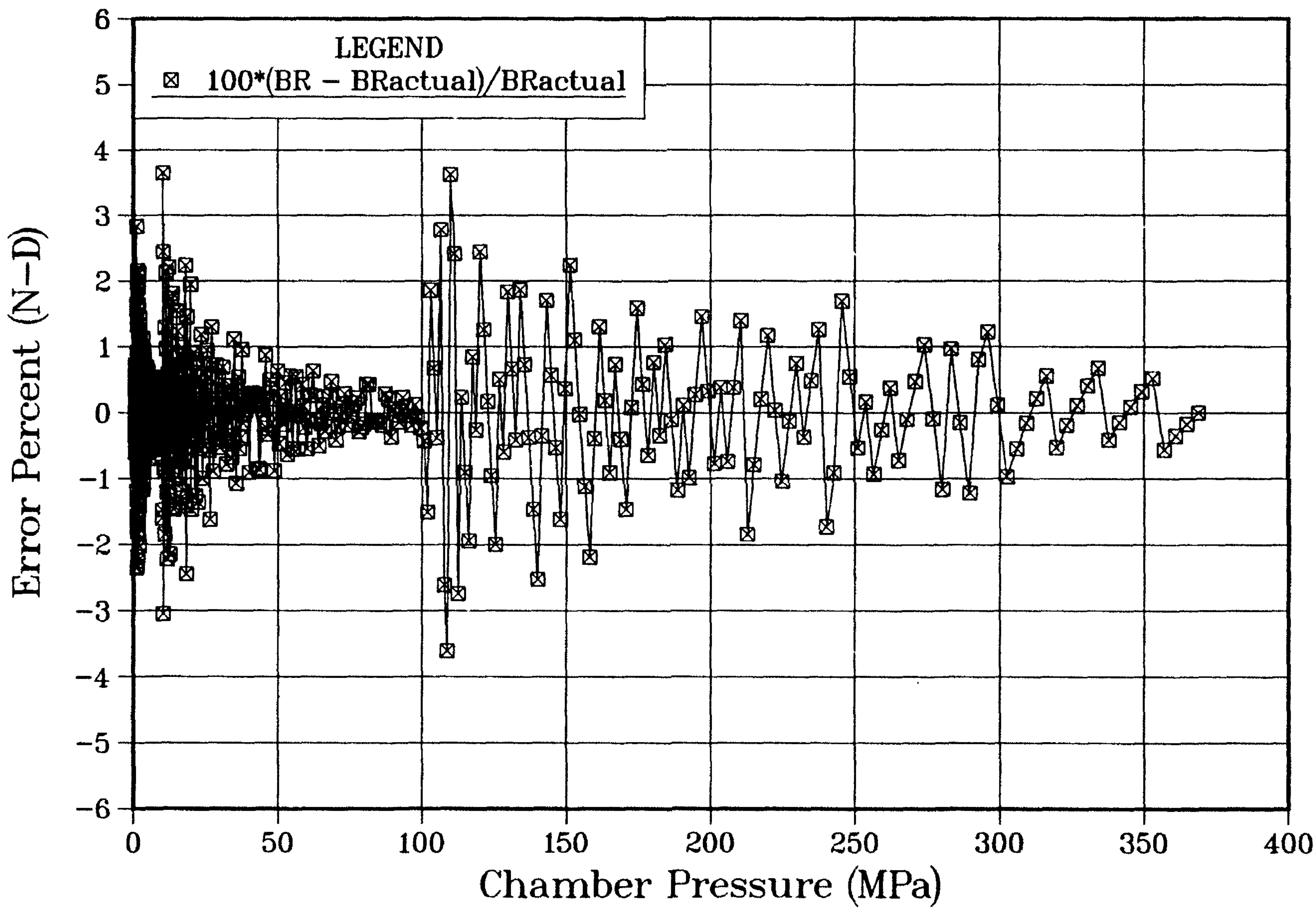

Figure 2. Synthetic test case: Percent error in BR using BRLCB with four-place accuracy.

Synthetic test cases of layered spheres with variable properties were also tested with errors on the order of hundredths of a percent (see Figures 3–5).

Comparative analysis with existing codes was on the order of 1%.

Typical run times, on a 12-MHz 286 PC-compatible computer, were on the order of 1–2 minutes for simple geometries (slab) and 6–7 minutes for more complicated geometries (19-perforated right circular cylinder). Graphics and smoothing processes exist, but it was suggested to use the Fast Fourier Transform only in the postprocessing of the BR data.

Dennis Worthington (Olin Corporation) discussed comparisons of layered ball propellant between BRLCB and an Olin-developed BR reduction code. There was good qualitative agreement (see Figure 6) with divergence noted at higher pressures (depth burned) by as much as 20% for more highly smoothed pressure-time curves (see Figure 7). Dennis concluded that further study is required for determining deterred propellant BRs and that input to BRLCB for deterred/layered calculations needs to be improved. It was agreed that a squashed ball form function should be included in BRLCB. Better mixing rules for different propellant gases may need to be considered for deterred/layered calculations.

Pam Kaste (BRL) discussed information she used in a D-BASE III database, which allows for the capability to see at a glance BR information on any sample and to sort on different fields. The contents of the database included identification, propellant characteristics, and BR in an aP^n format and at specified pressures.

Arpad Juhasz (BRL) could not attend, but left a viewgraph which brought up the nonsmooth nature of the BR analysis. Especially at low pressures, large oscillations in the BR are noted using pressure-time curves which are not smoothed to a large degree. Arpad suggested that codes which use dP/dt to get dx/dt sometimes give smoother BR vs. pressure curves and may be a preferable solution technique. However, other attendees felt that it was better to limit the smoothing to the derived result (BR), not the starting data (pressure-time curve). A possible solution if a smooth BR curve is desired would be to remove some of the data points or possibly have an electronic low-pass filter in the pressure-time acquisition system.

Closed - chamber volume: 300 cm^3					
Grain geometry: sphere (five layers) (.5 cm diameter)					
Starting depth: (cm)	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
	0.0	.0263	.06688	.1316	.23434
Propellant properties:					
Impetus (J/g):	382.5	540.4	803.7	1,064.2	1,398.3
Flame temperature (K):	2,300	2,600	2,900	3,200	3,700
Gamma (-):	1.27	1.26	1.25	1.24	1.22
Molecular weight (-):	50	40	30	25	22
Covolume (cm^3/g):	.95	.92	.89	.85	.80
Density (g/cm^3):	1.4	1.45	1.5	1.55	1.65
Total mass: 110 g + 2 g igniter					
Burn rate law (cm/s):	$r=1.0P^{.5}$	$r=.02P^{1.3}$	$r=.2P^{.9}$	$r=.01P^{1.1}$	$r=.05P^{1.3}$

Five Layer Sphere

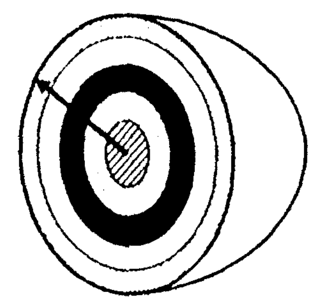

Figure 3. Test case conditions for five-layer sphere with constant properties.

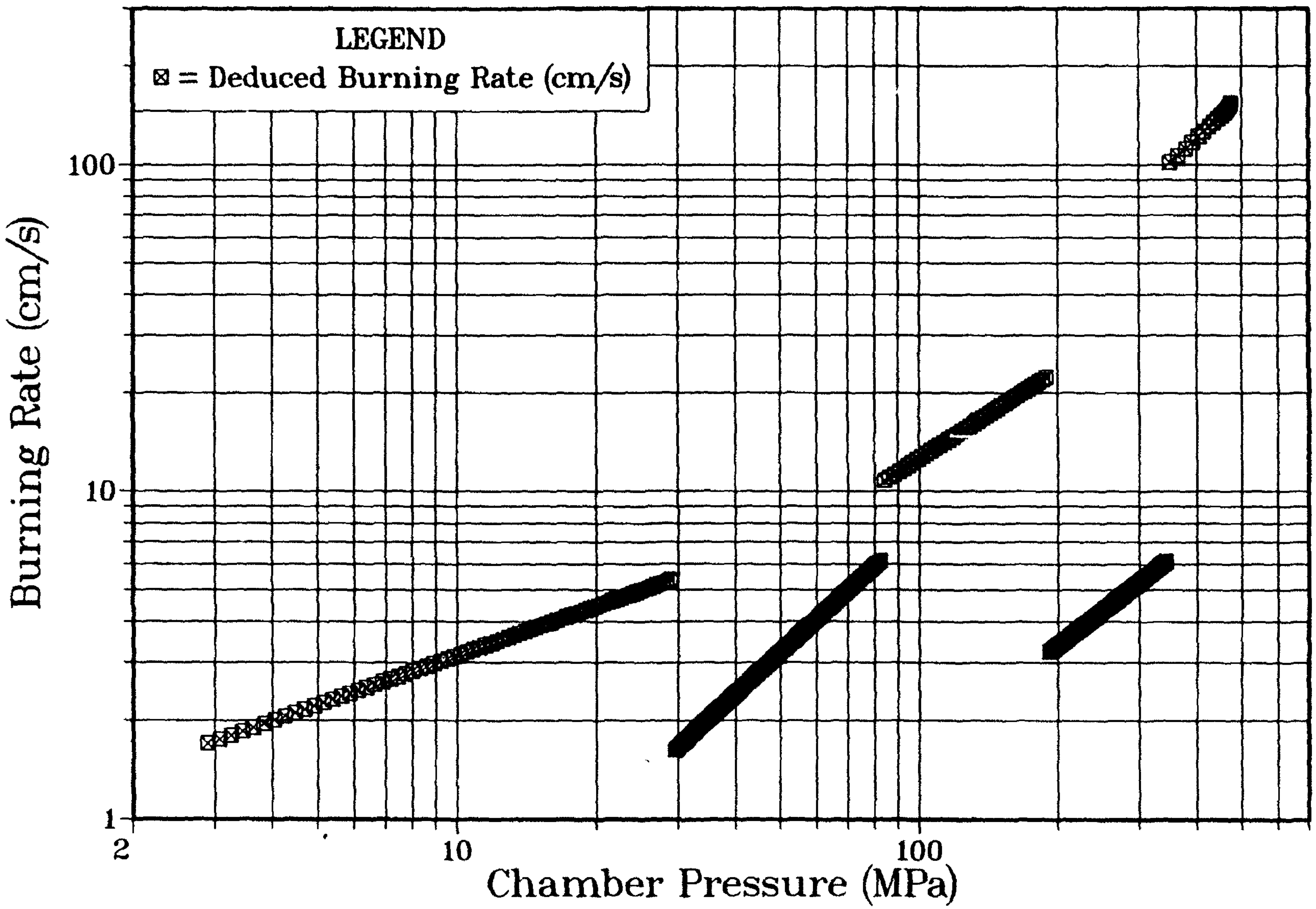

Figure 4. Deduced BR for five-layer, constant properties sphere using BRLCB.

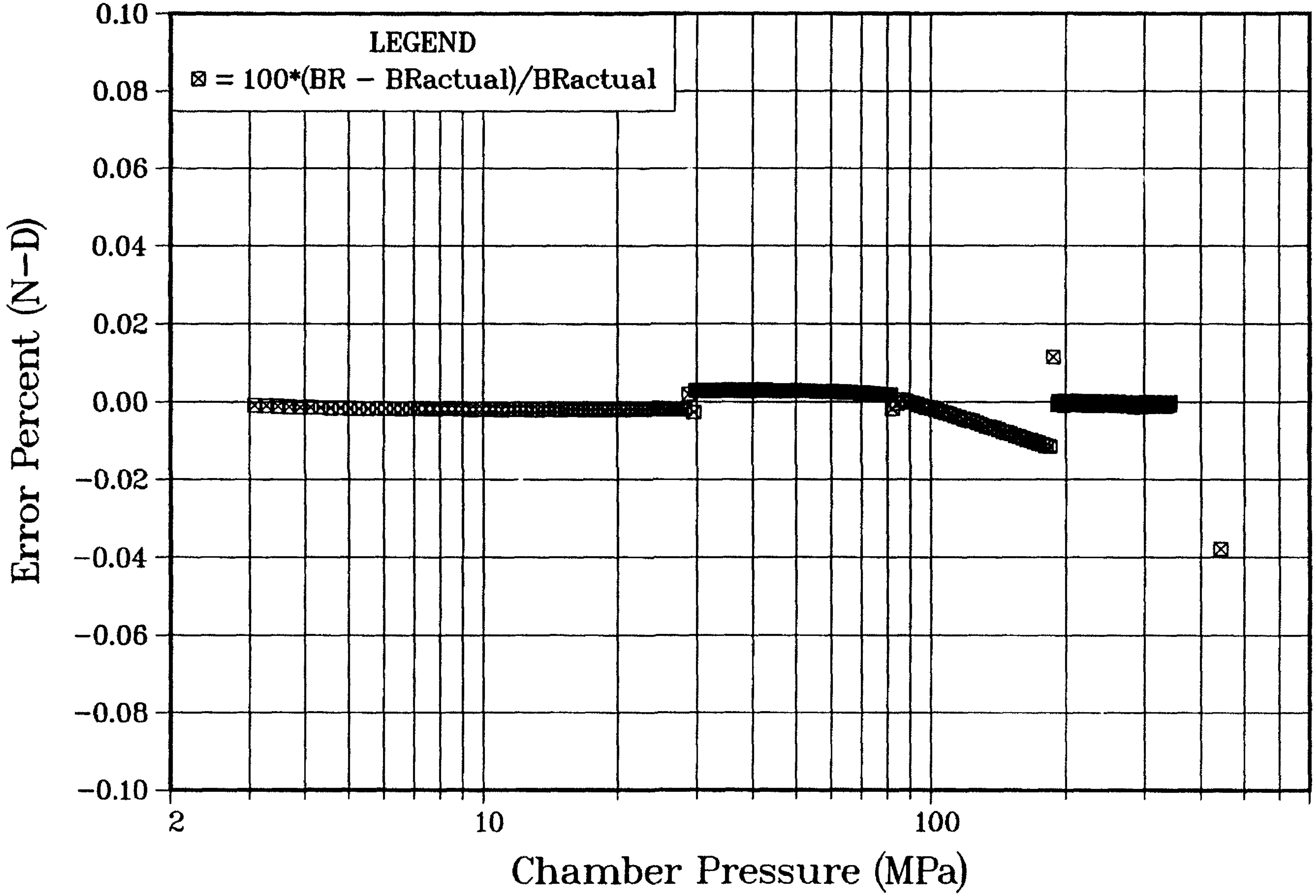

Figure 5. <u>BR uncertainty for the five-layer constant properties sphere test case.</u>

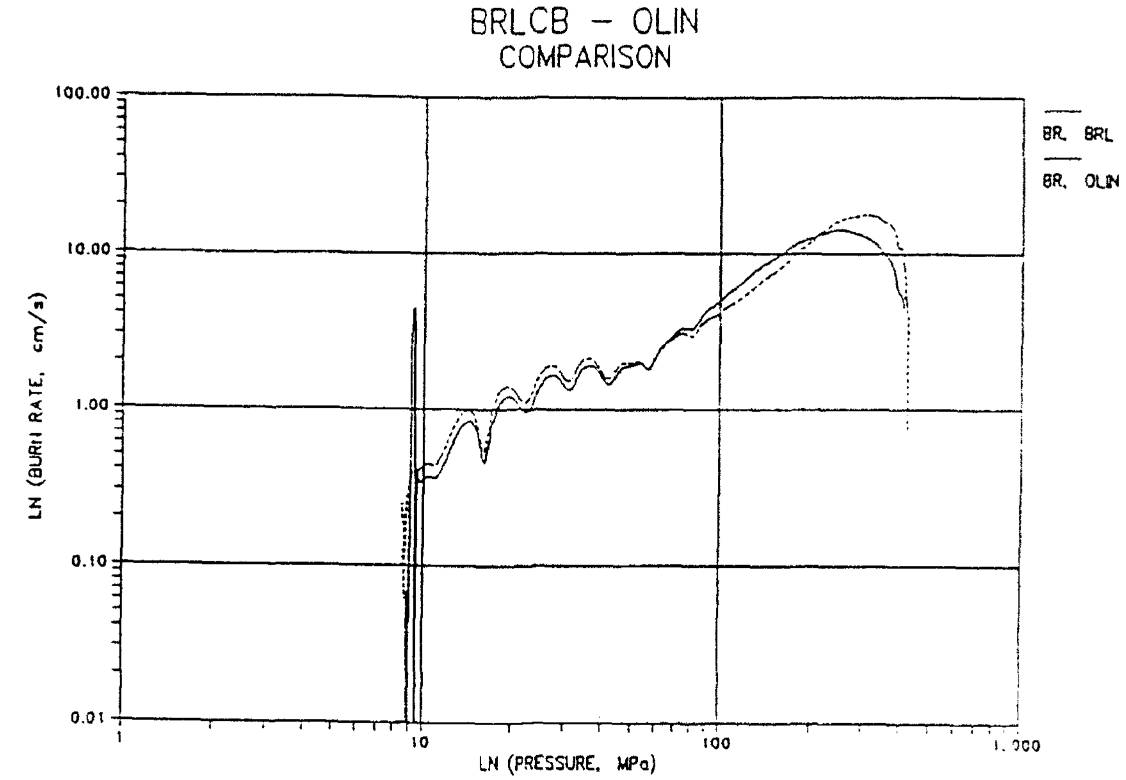

Figure 6. Comparison of BRs for layered ball propellants using BRLCB and an Olin-developed BR reduction code.

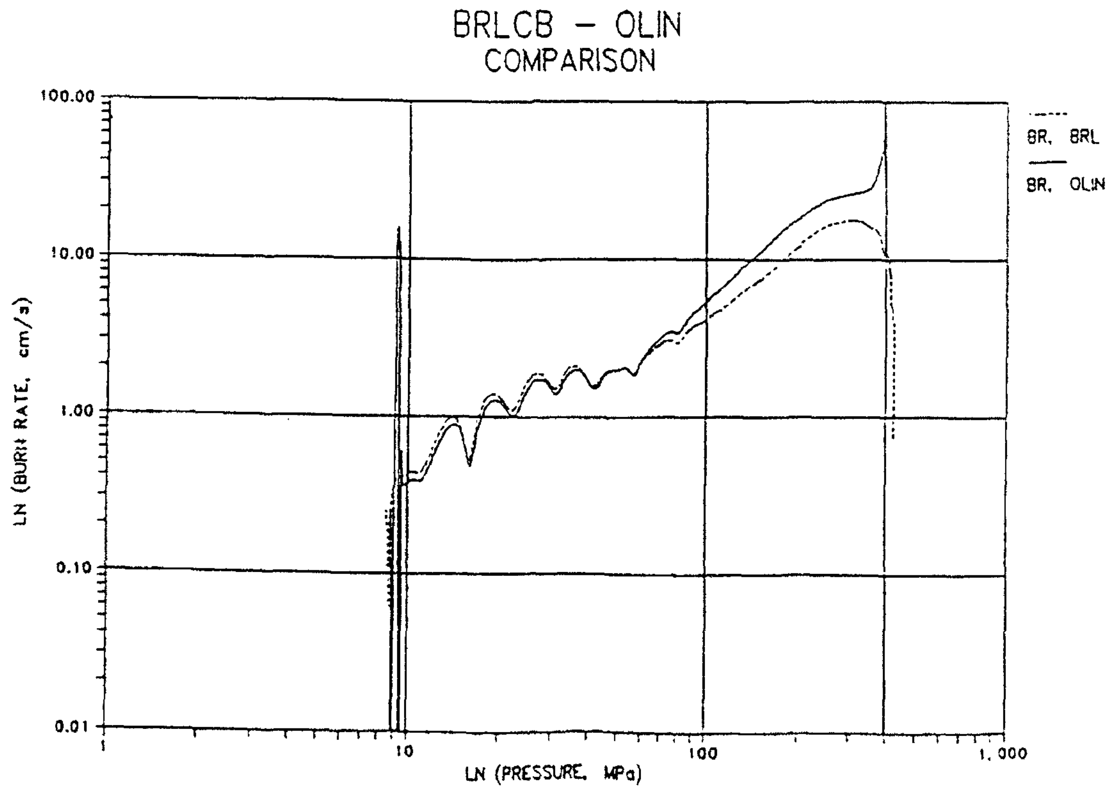

Figure 7. Comparison of BRs for a highly smoothed pressure-time curve.

John Domen (ARDEC) gave a history of attempts to standardize BR reduction as well as relative quickness and relative force for propellant manufacturers via military standard documentation. He had nearly completed getting the military standard accepted when the program was dropped due to lack of funds. Mil-Std 286b, method 801, describes closed bomb procedures for calculation of relative quickness and relative force.

The BR reduction code CCBA was described. CCBA calculates vivacity as well as linear BRs. The wild point and smoothing procedures in BRLCB were derived from the data preparation portions of CCBA. It was suggested that a quadratic fit for smoothing of the pressure-time curve was best.

Sharon Boyle (NSWC-IH) presented comparisons of BRLCB and YBOMB (BR reduction code used at Indian Head). The BR vs. pressure curves obtained from these two codes were virtually identical (see Figures 8–11). An error in the calculation of dP/dt (not used to deduce BR in BRLCB) was noted between version 2 and version 3 of BRLCB; this error was confirmed and has been fixed.

Dave Dillehay (Thiokol-Longhorn) went over procedures used to characterize rocket propellants at the Longhorn division of Thiokol. The procedures, empirical in nature, allow for the design and modifications of rocket motors.

D. A. Worrell (Hercules Radford) went over the capabilities at the Radford Army Ammunition Plant (RAAP) and procedures being followed now. RAAP has low-pressure bombs (up to 30 ksi) for doing relative quickness and relative force measurements. The gauges used in these bombs, though usable for relative measurements, may not be sufficient for getting linear BRs. The high-pressure bombs (up to 100 ksi) in conjunction with BRLCB data analysis are used to get linear BRs. Propellant description sheets can be modified to incorporate BR information. RAAP is in favor of establishing a plan to test protocol and the implementation of procedures. It would like to see a database developed and possibly a round robin verification of BRLCB.

Jerry Rubin (ARDEC) gave a status report of what STANAG 4115 on propellant properties is attempting to accomplish and the state of its development. The aim is to standardize the use of the closed bomb procedure for the determination of propellant burning properties for use in interior ballistic calculations (absolute measurements) and for quality control (relative measurements).

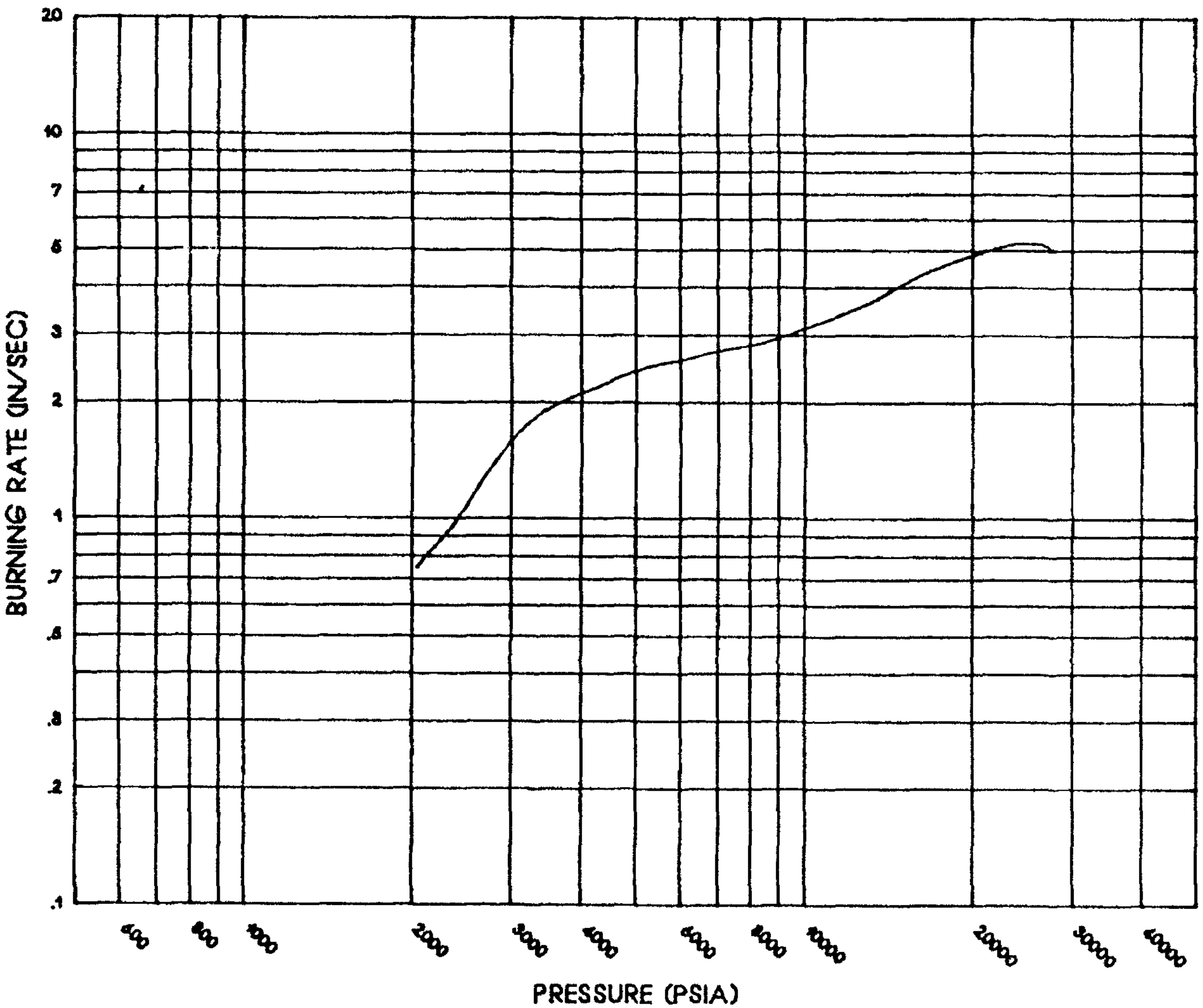

Figure 8. BR vs. pressure for M30 propellant: BRLCB reduction.

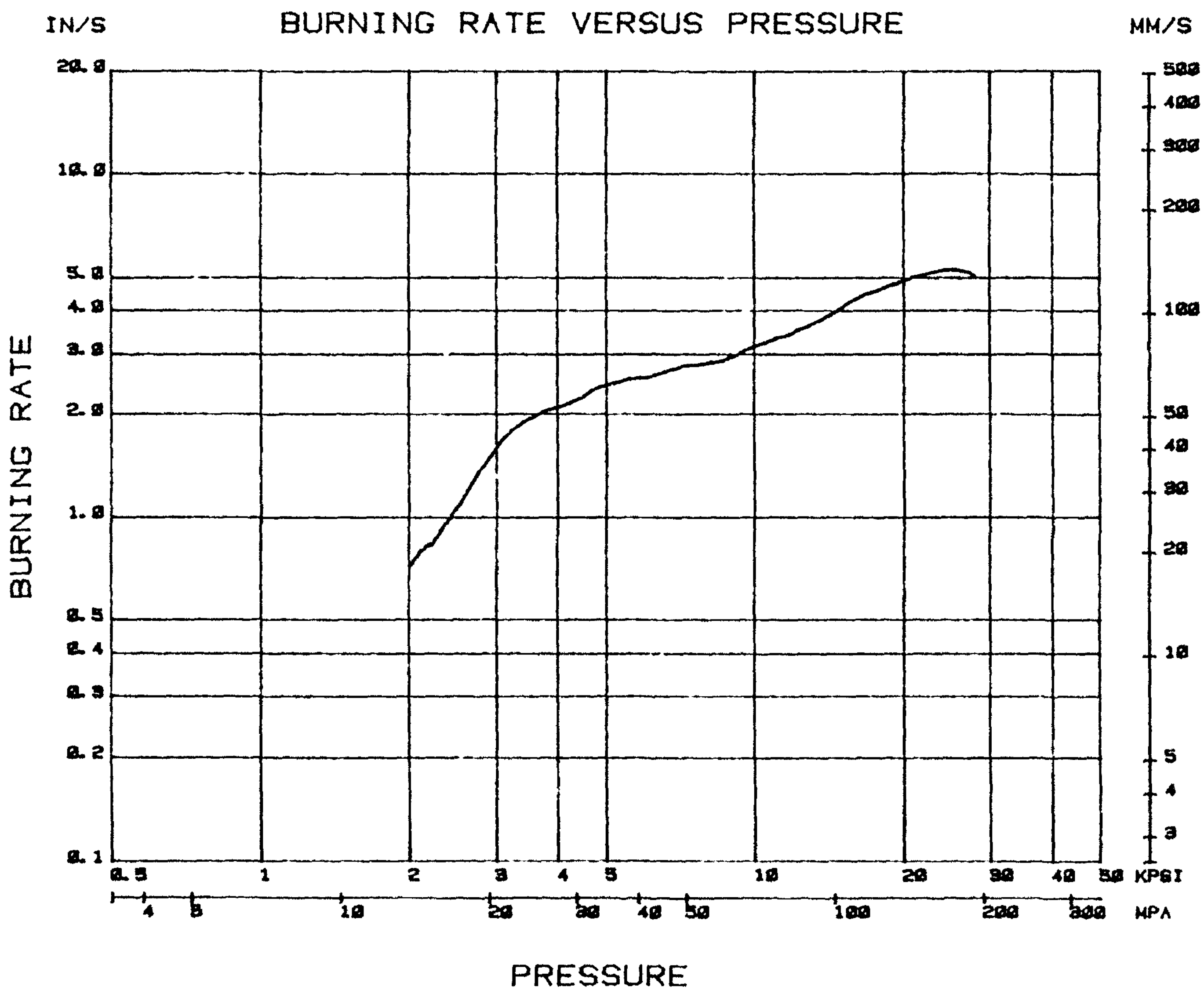

Figure 9. BR vs. pressure for M30 propellant: YBOMB reduction.

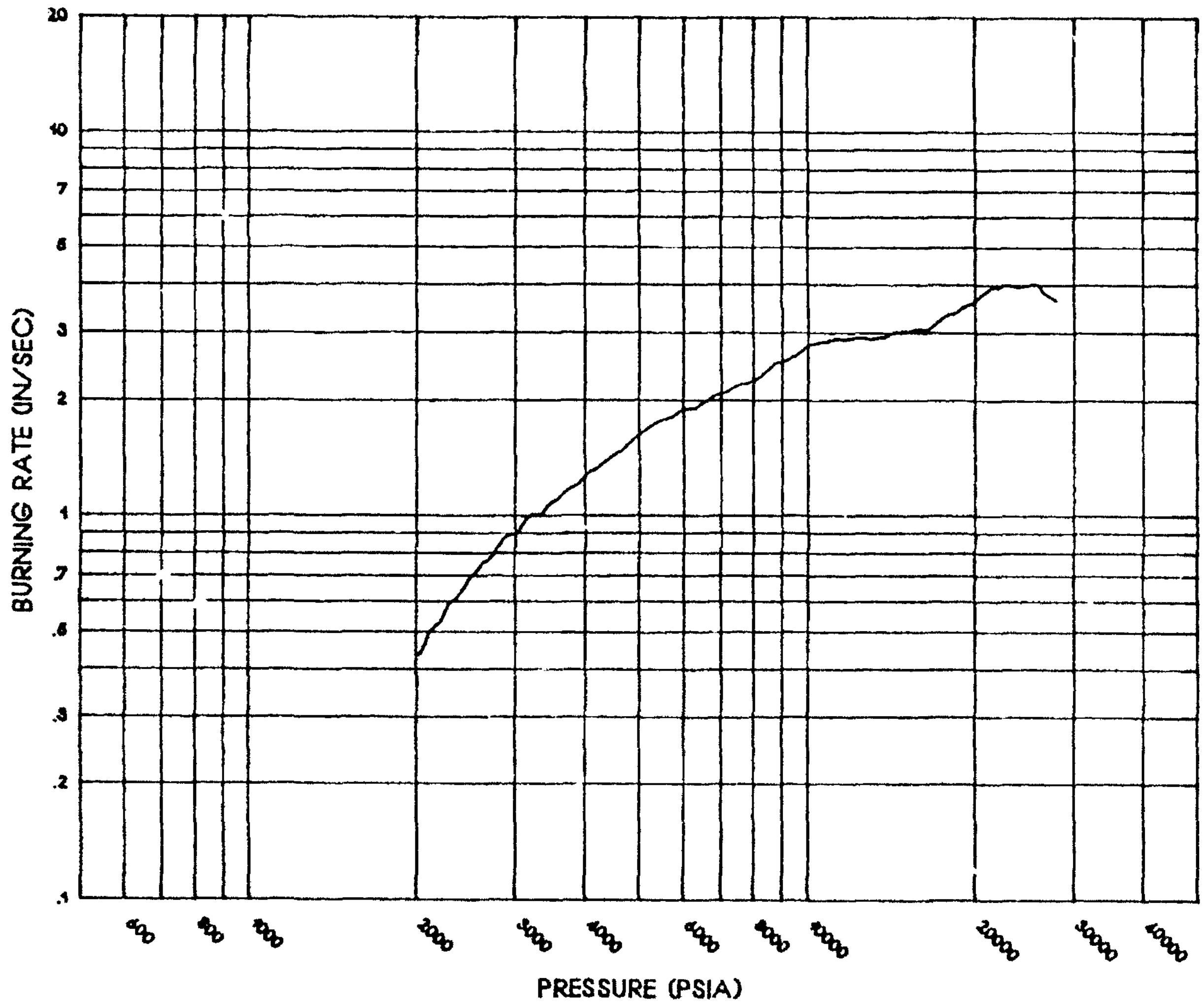

Figure 10. BR vs. pressure for LOVA propellant: BRLCB reduction.

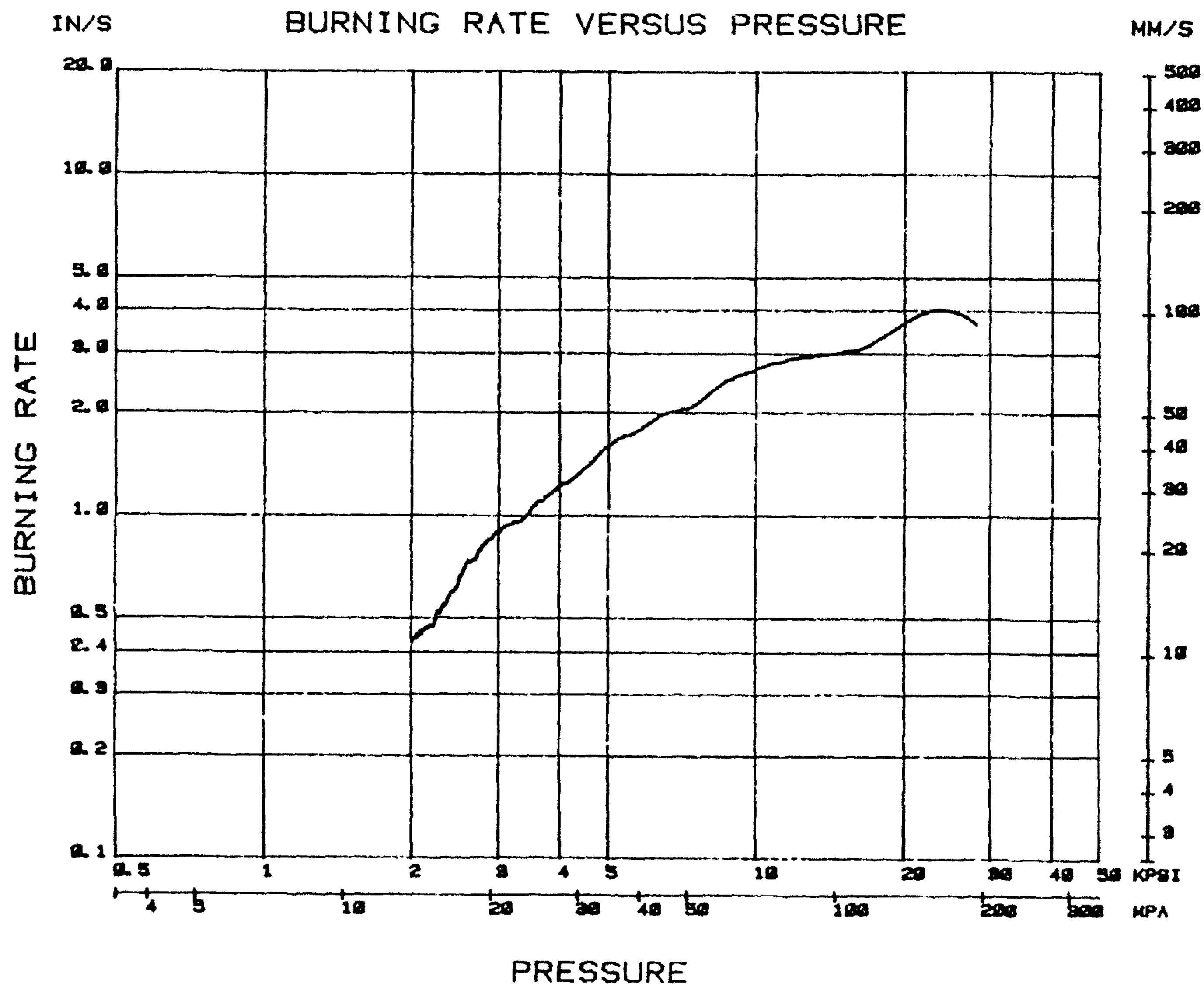

Figure 11. BR vs. pressure for LOVA propellant: YBOM.3 reduction.

Otto Heiney (from Rocketdyne) described a closed bomb reduction code being developed at Rocketdyne which uses similar procedures as YBOMB at Indian Head and CCBA at ARDEC (they require only covolume as a thermodynamic input but assume knowledge of heat loss and the igniter). There were some unexplained differences between BRLCB and his code.

Discussions were held on what assumptions are nearly universal in closed bomb BR reduction procedures. The set of assumptions defining a model is given in Table 1.

Not so universal characteristics in analyses used to get BRs are given in Table 2, and in Table 3, potential data acquisition differences are listed.

Much discussion centered around BRLCB as a possible "standard" closed bomb reduction code. It was finally agreed that "BRLCB is the interim preferred closed bomb code for all data exchange purposes; where an alternate code is used, then parallel reporting shall occur if possible."

Discussions as to what would be desirable information on propellant manufacturers' description sheets produced the following suggestions.

The linear BRs should be tabulated at 5-ksi intervals up to 30 ksi and every 10 ksi after that. The preferred code would be BRLCB. The thermochemistry should be calculated at 0.2 loading density and should include impetus, gamma, flame temperature, and covolume. Information should be included on the size of the bomb, amount and type of igniter, and loading density of the bomb. The absolute density and propellant grain dimensions should also be given. Units (metric/English) should follow military standards.

The problem of how to conduct and report BRs for deterred and layered propellants was suggested as a possible future workshop subject.

3. WORKSHOP PROGRESS

- A set of assumptions which embodies a BR reduction model was accepted.

- BRLCB was accepted as an interim preferred closed bomb code for all data exchange purposes.

- Suggested information to be incorporated into propellant description sheets was agreed upon.

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